Announcements

- **FINAL EXAM:**
  - PHYS 132-001: Wednesday, May 10 @ 10-11:50 am
- **Homework for tomorrow…**

  Ch. 23, Probs. 26, 27, 32 & 33

  23.14: 22°
  23.16: 23 cm
  23.18: 113 cm
  23.53: 1.1°

- **Office hours…**

  MW 10-11 am

  TR 9-10 am

  F 12-1 pm

- **Tutorial Learning Center (TLC) hours:**

  MTWR 8-6 pm

  F 8-11 am, 2-5 pm

  Su 1-5 pm

Chapter 23

Ray Optics
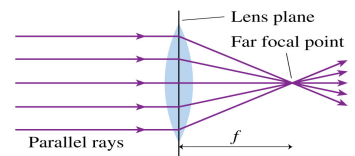
(Thin Lenses: Ray Tracing & Refraction Theory)

Last time...

- *Rayleigh Scattering...*

$$I_{scattered} \propto \frac{1}{\lambda^4}$$

Lens plane
Far focal point

Parallel rays f

Any ray initially parallel to the optical axis will refract through the focal point on the far side of the lens.

*Ray Tracing* through a thin *converging lens*...

1. A *parallel ray* will go through the *far focal point* after passing through the lens.

2. A ray through the *near focal point* of a thin lens becomes *parallel* after passing through the lens.

3. A ray through the *center* of a thin lens travels in a *straight line*.

Near focal point   Lens plane

f Parallel rays
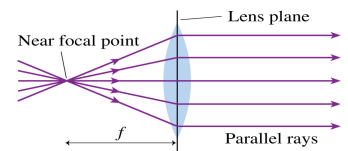
Any ray passing through the near focal point emerges from the lens parallel to the optical axis.

Center of lens   Rays are not bent.
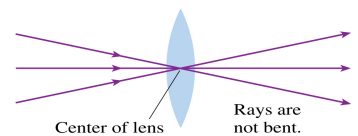
Any ray directed at the center of the lens passes through in a straight line.
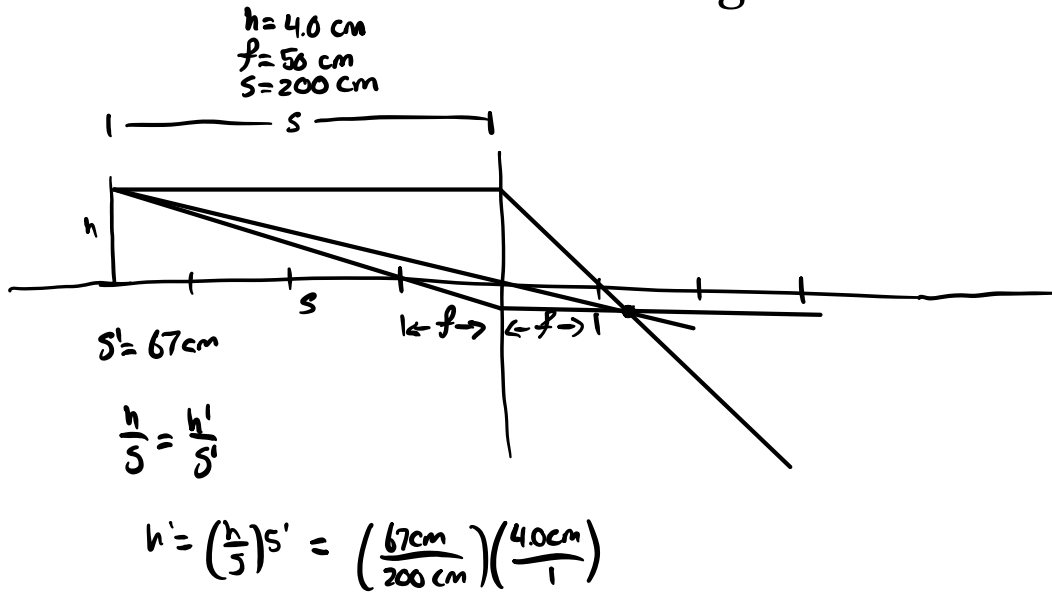
i.e. 23.8
Finding the image of a flower

A 4.0 cm diameter flower is 200 cm from the 50 cm focal length lens of a camera.

How far should the light detector be placed behind the lens to record a well-focused image?

What is the diameter of the image on the detector?

$h = 4.0$ cm
$f = 50$ cm
$s = 200$ cm

$s' = 67$ cm

$$\frac{h}{s} = \frac{h'}{s'}$$

$$h' = \left(\frac{h}{s}\right)s' = \left(\frac{67 cm}{200 cm}\right)\left(\frac{4.0 cm}{1}\right)$$

Lateral Magnification...

- The image can be either *larger* or *smaller* than the object, depending on the location and focal length of the lens.
- The *lateral magnification, m,* is defined as:

$$m = -\frac{s'}{s}$$

Notice:

- *Positive m = upright* image.
- *Negative m = inverted* image.
- The absolute value of *m* gives the size ratio of the image and object: $h'/h = |m|$.
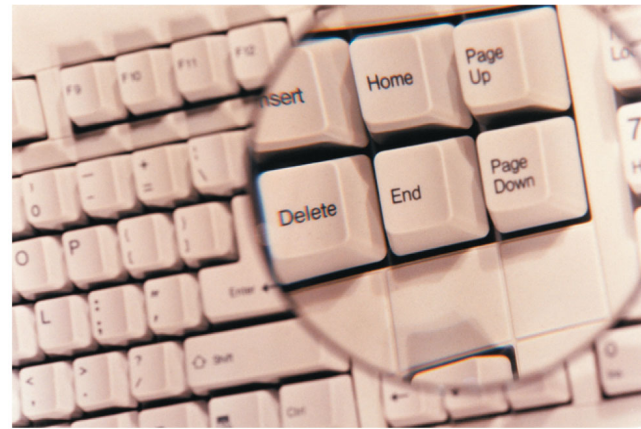
Virtual Images…

- Consider a *converging lens* for which the object is *inside* the focal point, at distance *s < f.*

- All 3 rays appear to *diverge* from point *P′.*

- Point *P′* is an *upright, virtual image* of the object point *P.*
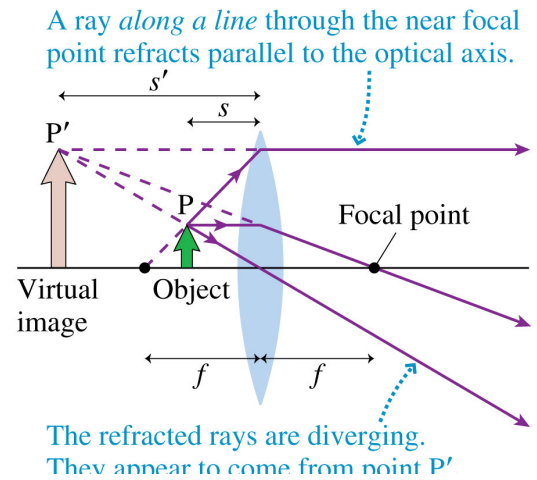
Notice:

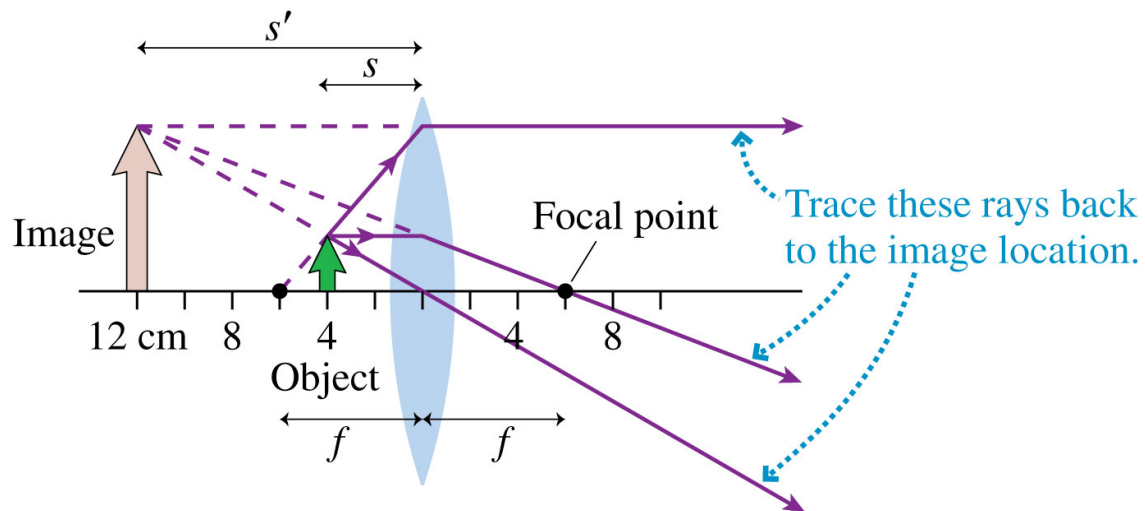☐ Image distance *s′* for a *virtual image* is *negative.*

s′

s

P′

P

Focal point

Virtual image

Object

f   *f*

(b)

i.e. 23.9:
Magnifying a flower

To see a flower better, a naturalist holds a 6.0 cm focal length magnifying glass 4.0 cm from the flower.

What is the magnification?

$s' = -12cm$

$s = 4cm$

$M = -\left(\frac{-12cm}{4cm}\right) = 3$

$M = 3$

$M = 3$

23.6
Thin Lenses: Ray Tracing

3 situations form the basis for ray tracing through a thin *diverging lens*.

1. A ray initially *parallel* to the optical axis will appear to diverge from the *near focal point* after passing through the lens.

2. A ray directed along a line toward the *far focal point* becomes *parallel* to the optical axis after passing through the lens.

3. A ray through the *center* of a thin lens is neither bent nor displaced but travels in a *straight line*.

Parallel rays

Near focal point

f
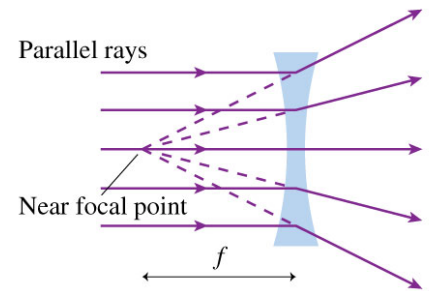
Any ray initially parallel to the optical axis diverges along a line through the near focal point.

Parallel rays

Far focal point

f
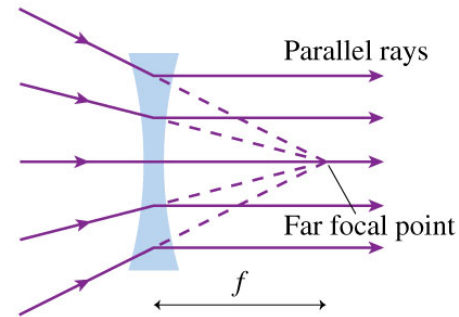
Any ray directed along a line toward the far focal point emerges from the lens parallel to the optical axis.

Center of lens   Rays are not bent.
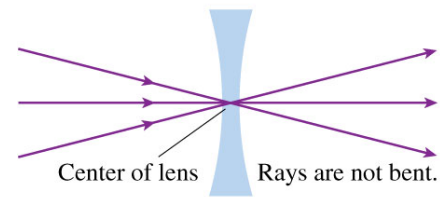
Any ray directed at the center of the lens passes through in a straight line.
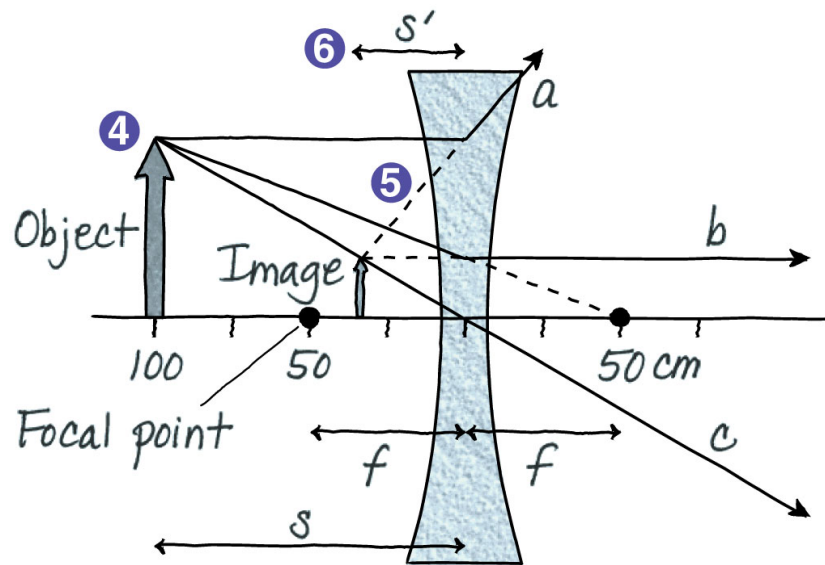
i.e. 23.10
Minify-ing a flower

A diverging lens with a focal length of 50 cm is placed 100 cm from a flower.

Where is the image?

What is its magnification?

$S = 100 \text{cm}$

$f = 50 \text{cm}$
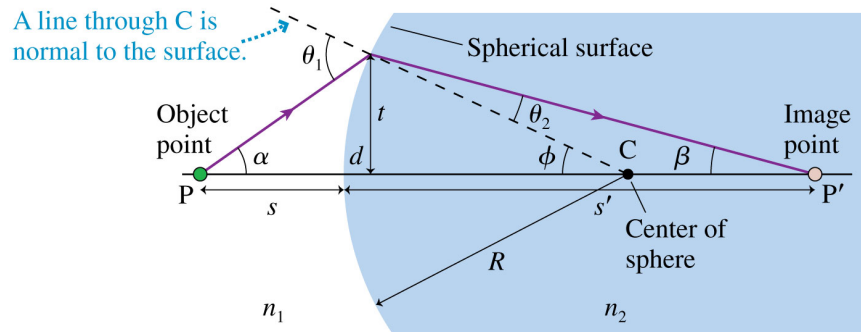
$S' = -33 \text{cm}$

$$M = -\frac{S'}{S} = -\frac{(-33\text{cm})}{100\text{cm}} = \frac{1}{3}$$

23.7:
Thin Lenses: Refraction Theory

- Consider a spherical boundary between two transparent media with indices of refraction n_1 and n_2.
- The sphere has radius of curvature R and is centered at pt C.

A line through C is normal to the surface.

θ_1

Spherical surface

Object point

t

θ_2

Image point

α

d

ϕ

C

β

P

s

s'

P$'$

Center of sphere

R

n_1

n_2

If an object is located at distance s from a *spherical refracting surface*, an image will be formed at distance s' given by:

23.7:
Thin Lenses: Refraction Theory

- Consider a spherical boundary between two transparent media with indices of refraction n_1 and n_2.
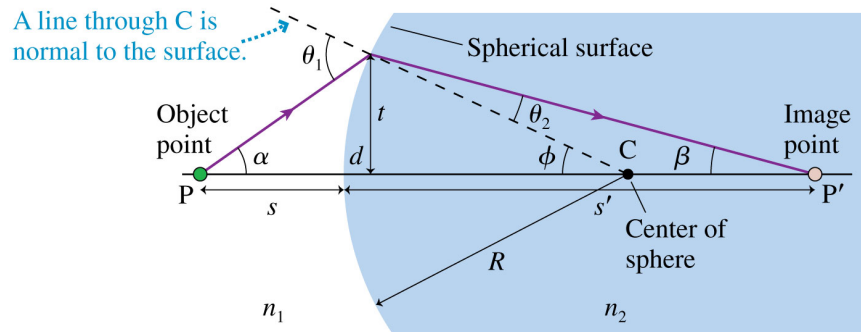- The sphere has radius of curvature R and is centered at pt C.

A line through C is normal to the surface.

Object point

Spherical surface

Image point

θ_1
θ_2
ϕ
α
d
t
C
β
P
P'
s
s'
Center of sphere
R
n_1
n_2

If an object is located at distance s from a *spherical refracting surface*, an image will be formed at distance s' given by:

$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R}$$

23.7:
Thin Lenses: Refraction Theory

If an object is located at distance *s* from a *spherical refracting surface*, an image will be formed at distance *s′* given by:
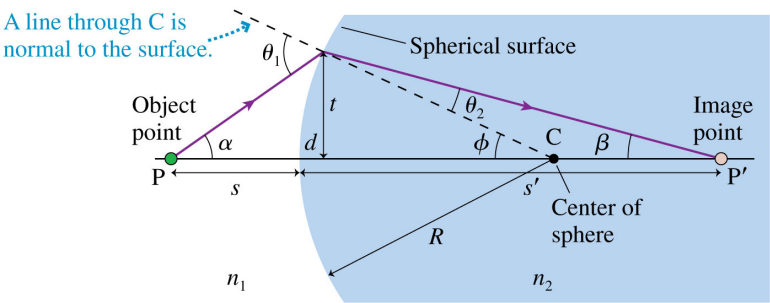
$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R}$$

TABLE 23.3 Sign convention for refracting surfaces

	Positive	Negative
R	Convex toward the object	Concave toward the object
s'	Real image, opposite side from object	Virtual image, same side as object

i.e. 23.11:
Image formation inside a glass rod

One end of a 4.0 cm diameter glass rod is shaped like a hemisphere. A small light bulb is 6.0 cm from the end of the rod.

Where is the bulb's image located?

$$n_1 = 1.00$$

$$n_2 = 1.50$$

$$2R = 4.0 \text{ cm}$$

Object

Image

$$s = 6.0 \text{ cm}$$

$$s'$$
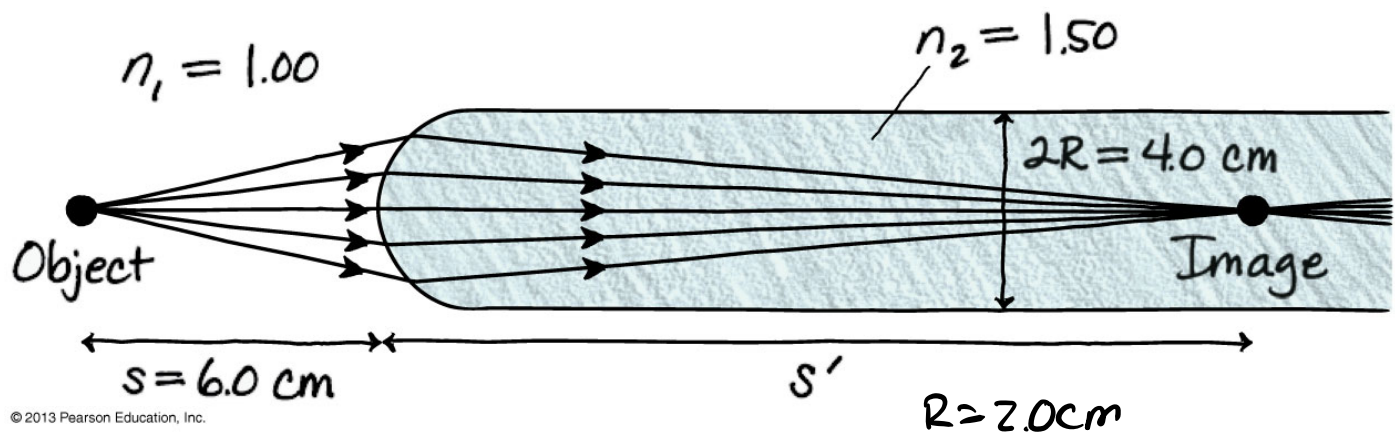
$$R = 2.0 cm$$

$$\frac{n_1}{S} + \frac{n_2}{S'} = \frac{n_2 - n_1}{R}$$

$$\frac{1.00}{6cm} + \frac{1.50}{S'} = \frac{0.5}{2cm}$$

$$S' = 18cm$$

$$R = 2.0cm$$
$$S = 6.0cm$$
$$n_2 = 1.50$$
$$n_1 = 1.00$$

i.e. 23.12:
A goldfish in a bowl

A goldfish lives in a spherical fish bowl 50 cm in diameter. If the fish is 10 cm from the near edge of the bowl, where does the fish appear when viewed from the outside?

$R = 25cm$

$n_1 = 1.33 \quad n_2 = 1.00$

$\dfrac{n_1}{s} + \dfrac{n_2}{s'} = \dfrac{n_2 - n_1}{R}$

$s = 10cm$

i.e. 23.12:
A goldfish in a bowl

A goldfish lives in a spherical fish bowl 50 cm in diameter. If the fish is 10 cm from the near edge of the bowl, where does the fish appear when viewed from the outside?

$n_1 = 1.33$

$R = -25$ cm

$n_2 = 1.00$

Object

Virtual image

$s = 10$ cm

s'